VEHICLE TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Overview and Progress of Applied Battery Research (ABR) Activities

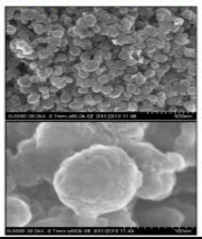
June 7, 2016

Dr. Peter Faguy

Strategy: Integrated Portfolio

Advanced Materials Research

SEM of Li_2FeSiO_4/C nanospheres

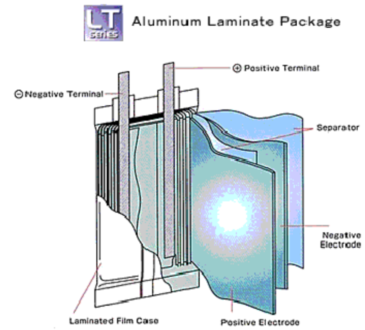


- ❑ High energy cathodes.
- ❑ Alloy, lithium metal anodes.
- ❑ High voltage electrolytes.
- ❑ Solid State.

Cell Materials Targets

- ❑ Anode capacity >1,000mAh/g.
- ❑ Cathode capacity >300mAh/g.
- ❑ High-voltage cathodes & electrolytes stable up to 5 V.
- ❑ Solid-polymer electrolytes with >10^{-3} S/cm ionic conductivity.

High Energy & Power Cell R&D



- ❑ High energy couples.
- ❑ High energy and rate electrodes.
- ❑ Fabrication of high E cells.
- ❑ Cell diagnostics.
- ❑ Improved manufacturing processes.

Cell Targets

- ❑ 350 Wh/kg.
- ❑ 750 Wh/Liter.
- ❑ 1,000 cycles.
- ❑ 10+ calendar year life.

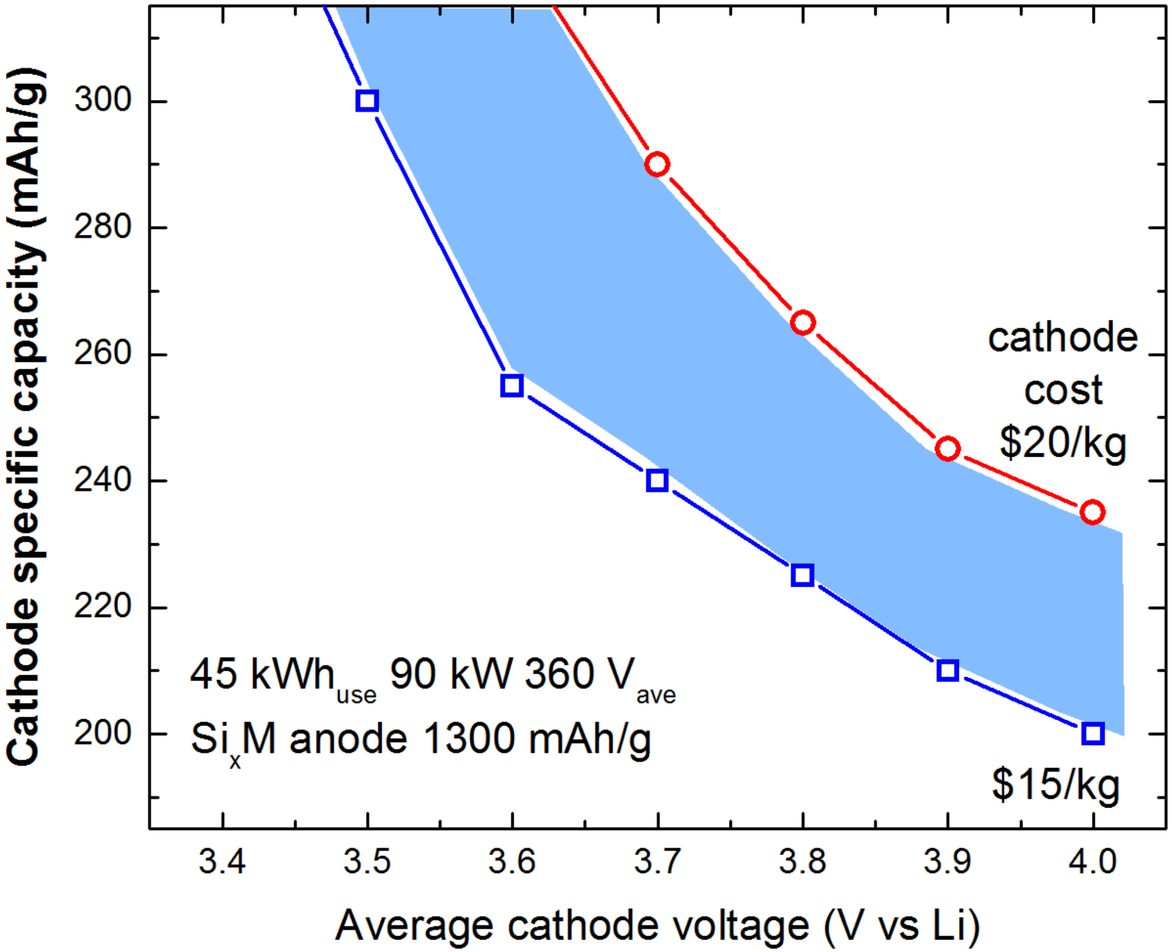
Full System Development & Testing

- ❑ Focus on cost reduction, life and performance improvement.
- ❑ Robust battery cell and module development.
- ❑ Testing and analysis.
- ❑ Battery design tools.

Battery Pack Targets

- ❑ $125/kWh EV pack cost.
- ❑ Fast charge (80% SOC in 15 minutes).
- ❑ $180 12 V start/stop pack cost.

Requirements to meet USABC EV Targets



- One example of a Si_XM anode that achieves 1300 mAh/g:
  - 30wt% silicon, 70 wt% graphite for active material.
  - electrode uses 80wt% active, 10wt% c-black and 10wt% binder.

Applied Battery Research Portfolio

- Research projects with a significant materials development/optimization component
  - Project deliverables involve full cell evaluations and significant characterization and diagnostic effort
  - Current project mix:
    - Cell optimization
    - Deep dive projects
    - Process-based R&D
    - Improved High Energy Cells for PEV Applications

Cell Optimization Projects

- ❑ Cell Analysis, Modeling, and Prototyping (CAMP) Facility Research Activities
- ❑ Materials Benchmarking Activities for CAMP Facility
- ❑ Materials Scale Up Facility
- ❑ Post-Test Analysis of Lithium-Ion Battery Materials

ANL Advanced Processing and Battery Materials Accomplishments

- Argonne's Materials Engineering Research Facility (MERF) facilities were established to scale up promising exploratory materials and help expedite the transfer of advanced battery materials from the lab bench to industry.
  - In 2015, Strem Chemicals, licensed 23 pieces of intellectual property from Argonne and will distribute nine battery solvents and redox shuttles.
  - In 2016, Aldrich licensed 10 pieces of intellectual property from Argonne and will distribute one redox shuttle and two electrolyte solvents.
- Argonne will be providing Aldrich and Strem technology transfer packages that detail:
  - the exact material specifications; and
  - economical materials synthesis and process validation procedures.

The MERF produces kg level quantities of new battery materials using scalable manufacturing processes to enable testing in industrially relevant sized cells and faster adoption by industry.

Characteristics of Deep-dive Projects

THE PROJECT

- ❑ Project thrust addresses a barrier.
- ❑ Significant scientific and pre-commercial mitigation/adaptation efforts have already take place.
- ❑ Enabling multiple commercial paths forward.

THE APPROACH

- ❑ Multi-lab consortium with significant and sustained DOE support.
- ❑ Single lab as lead organization.
- ❑ Utilize competencies at individual labs to build synergism for team-based goals & task development.
- ❑ Develop rigorous common test vehicle (1/2 cell, full cells, electrolyte composition), measurement, and nomenclature platforms.
- ❑ Foster consensus approach to decision-making.

High Energy, High Voltage Deep Dive

High Energy/ High Voltage Cathode Project

2015-TBD

Multi-Lab/Multi-Disciplined Team

6 Labs

$4M per year

- Enable the use of cathode materials at >4.4 V.
- Target: 4.7-5.0 V (300 mAh/g).
- Focus: Layered Cathodes.
- Thrusts include electrolytes and additives; surfaces and interfaces; cell testing and analysis; theory and modeling.
- Key team members include:

Three talks, Wednesday afternoon

Enabling HE, HV Li-Ion Cells for Transportation Applications: Project Overview

Enabling HE, HV Li-Ion Cells for Transportation Applications: Materials Characterization

Enabling HE, HV Li-Ion Cells for Transportation Applications: Modeling and Analysis

Silicon Anode Deep Dive

Silicon Anode Deep Dive Project

2016-TBD

Multi-Lab/Multi-Disciplined Team

5 Labs

$5M per year

- ❑ Enable the use of intermetallic silicon composite anodes.
- ❑ Target: 1,000^{+} mAh/g and 1,000 EV Cycles.
- ❑ Focus is on:
  - Improving alloy material characteristics.
  - Development of more durable material binders.
  - Investigation surface modifications and advanced coatings.
- ❑ Key team members include:

Two talks, Wednesday afternoon

Next Generation Anodes for Lithium-ion Batteries: Overview

Next-Generation Anodes for Li-Ion Batteries: Fundamental Studies of Si-C Model Systems

Improved High Energy Cells for PEV Applications

Goal: Overcome key critical barriers to the production of high energy cells for PHEVs and EVs.

Program focused on

- High energy cell chemistries
- 1,000 EV cycles, 5,000 PHEV cycles
- 10-15 year calendar life
- Increased abuse tolerance

Summary of FY2012 Cell Targets

Requirements	PHEV40	EV
Discharge Pulse Power (W/kg)	800	800
Regen Pulse Power (W/kg)	430	400
Specific Energy (Wh/kg)	200	400
Energy Density (Wh/l)	400	600
Calendar Life (years)	10+	10
Cycle Life (cycles)	5,000	1,000

Where we were in 2012

- Those look like reasonable goals today, but remember where EV cells were in 2012 (not so long ago)

2012 EV Cell Status	EV Cell Target
~160 Wh/kg	400 Wh/kg
~300-350 Wh/l	600 Wh/l
240 W/kg (discharge)	800 W/kg
120 W/kg (regen)	400 W/kg

- These were very aggressive, stretch goals.

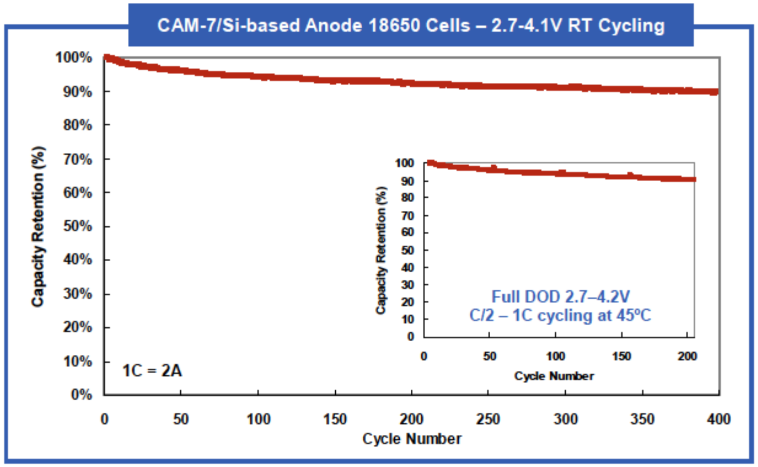
Awardees

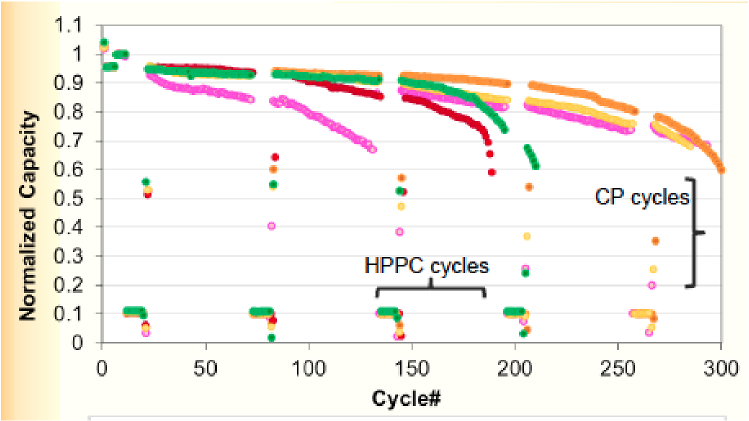
- In 2013, six new contracts were awarded to pursue the high energy cell goals:

- Each proposed an alloy anode and a high energy, normally high voltage, cathode, including concentration gradient or core/shell particle designs. All were capable of meeting the program targets.

Highlights and Remaining Issues

- Later today you'll hear about each of these six projects in more detail, here I will just highlight a couple of items:
  - Cells with >220Wh/kg, 600Wh/l have been made, but cycle life is a major challenge for most. Best performing cells, at 200Wh/kg, show 400 cycles and 10% capacity fade
  - A fluorinated solvent extend cycle life of HE NMC cells cycled to 4.5V by over 50%.
  - Coatings do not significantly improve life.

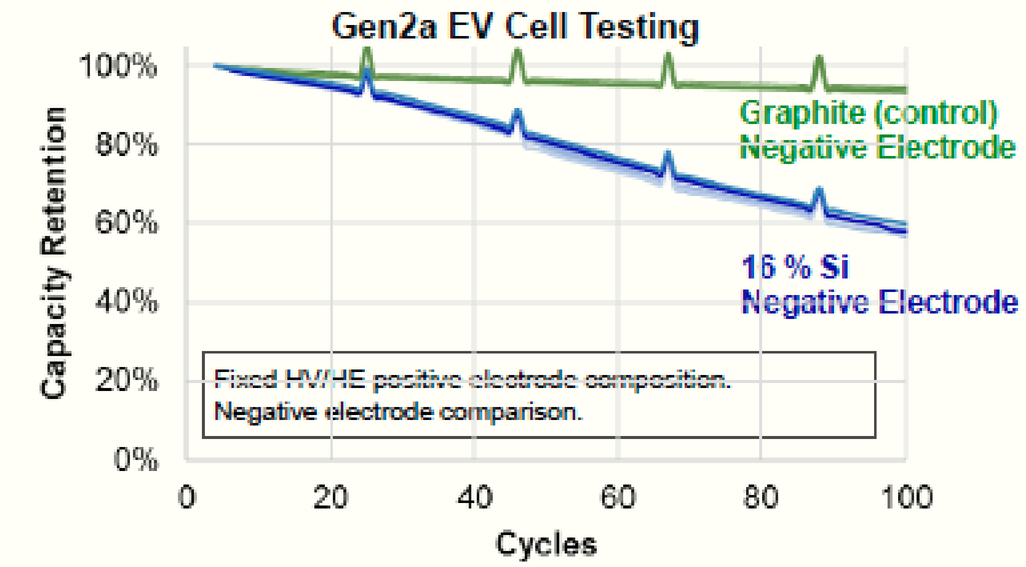




Highlights and Remaining Issues

- Nearly all developers concur that Si (and in general, alloy) SEI instability underlies the poor cycle and calendar life of Si based cells. There is emerging data indicating that the SEI in not stable under either cycling or calendar aging.

- We believe that more focused work is needed to understand this failure mode and develop mitigation techniques.



New Advanced Processing Technology Awards

24M	Semi-solid Li ion - simpler cell construction.
LAMBDA TECHNOLOGIES	Microwave electrode drying
MILTEC	UV electrode drying
parc A Xerox Company	Novel electrode structure with both high energy and power regions
PPG	Electrolytic electrode deposition process
NAVITAS SYSTEMS	Nano composite Si manufacturing process
VANDERBILT	Novel Processing of Electrospun Silicon Anodes

ABR Contact Information

Peter Faguy

Peter.Faguy@ee.doe.gov